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The Significance of Genetic Representation in Genetic Antenna Design

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Abstract *Genetic algorithms have been shown to be effective in the design of small antennas. However, their effectiveness depends on both the mechanisms of the genetic algorithm and the genetic representation of the problem. Here we present three genetic chromosome representations for a small antenna design problem (lowest VSWR for a specified h/λ cube size) and compare the results of the three optimization processes. Our work shows that different chromosome representations lead to solutions in different, overlapping subclasses, and that an important consideration in genetic antenna design is finding a simple chromosome representation which is capable of representing the subclass containing the "optimal" solution. Our initial results show that the chromosome design itself is an important factor in successful genetic antenna design.*

1. Introduction

Genetic algorithms (GAs) have emerged over the past decade as an important tool for designing antennas ranging from electrically small antennas to loaded monopoles and ultra wide-band antennas. [1,2,3,4,5]. In many cases, new types of non-intuitive solutions have emerged broadening the understanding of that particular discipline. However, it is often difficult and sometimes impossible to determine if one has achieved *the optimal solution*. An often unanswered question is: Is this really the best solution (or at least one of several equally-good solutions) for the problem constraints or has the genetic algorithm gotten stuck in or converged to a non-optimal solution. A second, equally-different question is: Does the genetic chromosome representation allow for the most general solution possible? Or could the optimal solution lie outside of the subset of problem solutions that the chromosome can represent?

We illustrate the importance of this second question by comparing three different chromosomes for optimizing the electrically small bent single-wire antenna element problem. This research expands upon previous work in this field [1,5] by comparing two new chromosome representations against the original problem representation. It is clear from the three types of antennas emerging from these different representations that *the genetic chromosome representation in genetic algorithm design is significant and not all methods of encoding the problem yield identical results*.

2. Review of Coordinate-Based Chromosome Work

The original electrically small bent wire genetic antenna designs by Altshuler [1] and Altshuler/Linden [5] formulated the antenna physical model as a fixed number of straight wire segments connected in series at their endpoints (called "nodes"). The chromosome representation for this model consisted of a string of x, y, and z Cartesian-space coordinates for each of these nodes, as shown in Fig. 1. Chromosomes were originally coded using 5-bits for each coordinate [5]; however in subsequent work, a real-valued GA was utilized and the coordinates represented by positive real values (vs. binary coding) [1].

Regardless of whether the coordinates are represented in binary or real-value coding, the **coordinate-based antenna chromosome representation** has both benefits and limitations. As described in [5], the number of straight wire segments or pieces needs to be determined before

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starting the GA (with up to 12 pieces supported in the physical code). This does not allow for a gradually-curving solution (such as a normal-mode helix) to emerge from the genetic “soup”, unless the GA was expanded to many more nodes. Hence, this chromosome representation limits the solutions resulting from this GA to only antennas having n straight wire pieces, where n is determined *a priori* by the user. However, it is worth noting that Altshuler found that, in general, there was not a significant improvement if more wires were used for a volume in which a resonant antenna having fewer wires could be obtained [1].

A nice feature of the coordinate-based chromosome representation is that the total length of wire comprising the antennas does not need to be determined *a priori*. Altshuler also noted in [1] that the resulting total length of wire the makes up the antenna was usually between .25 and .35 λ and that the length did not change systematically as the enclosing volume changed. A second general feature of the coordinate-based chromosome representation is that the resulting lengths of straight wire pieces may come out any size (fitting within the volume, of course, and greater than the minimum NEC segment size for that wire diameter).

A second limitation, besides the inability of this chromosome to represent curving shapes, is that the genetic algorithm did not proceed well when the half-space of all positive z-values was used. Hence, a decision was made to start the first wire from the origin and only proceed in the positive values quadrant. This design decision limits the subset of antennas resulting from this GA to only asymmetric antennas fed from the corner of the volume, as illustrated in Figure 1.

3. Angular-Based Chromosome Design

To eliminate some limitations (while introducing new ones), we recently experimented with an **angular-based chromosome**. In this approach, the antenna is modeled as a single piece of wire, broken into many fixed-length segments. The chromosome representation of an antenna is the azimuth and elevation angles of each segment. We coded these angles into a cyclic gray-code binary representation to eliminate Hamming cliffs between consecutive angle representations; this had the added benefit of crossing seamlessly in angular representation from 2π back to 0.²

There are two immediate sub-models that come to mind: **absolute angle** and **relative angle**. In the first, the azimuth and elevation angles are absolute to a fixed origin in spherical space, as shown in Fig. 2. In the second sub-model, the orientation of each segment is specified relative to the vector orientation of the previous segment, shown in Fig. 3. For relative-angle first segment, it is assumed that the previous segment lies along the z-axis. For both angular chromosomes, the first azimuth angle is removed and fixed to be 0 to eliminate competing identical solutions.

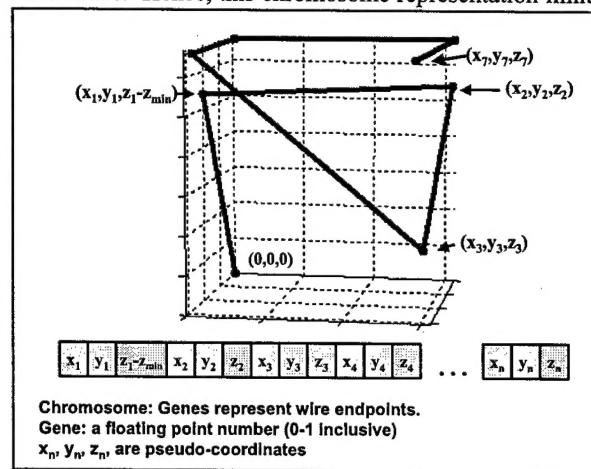


Fig. 1. The real-valued coordinate-based genetic antenna chromosome and a typical resulting antenna.

² A Hamming cliff arises when the number of bits needed to cross from one value to the next value is large, e.g. in binary coding from a 7 (0111) to an 8 (1000). This requires four bits to change, which would be an unlikely random mutation. A Hamming code has always one-bit difference between consecutive value representations. The cyclic gray code is a Hamming code where the highest value is also Hamming distance 1 from the lowest value.

Because the antenna structure is allowed to roam anywhere within the upper hemisphere, symmetric antennas are possible in this solution subset. Also, since many short segments are used in the relative-angle model, these are capable of representing curvy antenna structures, like a normal mode helix.

A drawback to the angular models is the *a priori* decision of antenna length. This is solved by running the GA for several different total wire lengths and

determining which works best for a given cube size. A second limitation is that, since all segment lengths are identical, antennas that would have optimum wire pieces slightly different from the chosen segment size are not possible. Since a very short piece-size is used, longer wire lengths result by combining many short pieces into a straight line. However, it is clear that these chromosome designs also limits the resulting genetic antennas into a particular subset of all possible solutions.

4. Initial Comparison of Methods

In Fig. 4, we show preliminary results comparing absolute angle and relative angle chromosome antennas to the previous coordinate-based chromosome results. To date, we have concentrated on optimizing the GA parameters for 0.05λ cube size. Within this region, the absolute angle-based chromosome produced a "best" antenna (in Fig. 2) with similar VSWR to the "best" coordinate-based chromosome antenna. However, the relative angle-based chromosome produced a "best" antenna (in Fig. 3) which has a VSWR $\sim 1/3$ lower than the comparable coordinate-based genetic antennas. A preliminary second result at the $.035 \lambda$ cube size indicates

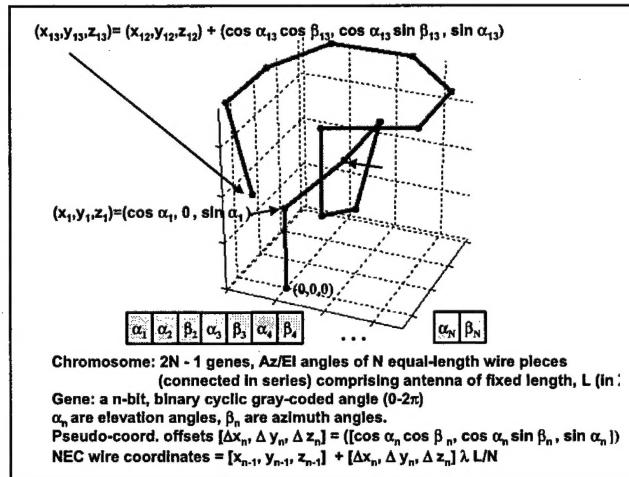


Fig. 2. The absolute angle genetic antenna chromosome and a typical resulting antenna.

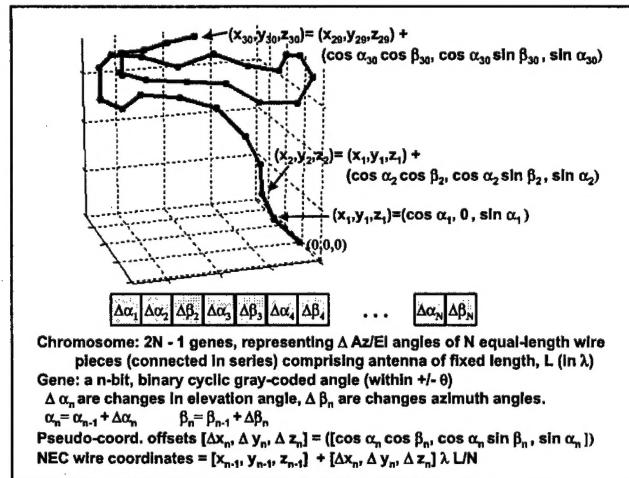


Fig. 3. The relative angle genetic antenna chromosome and a typical resulting antenna.

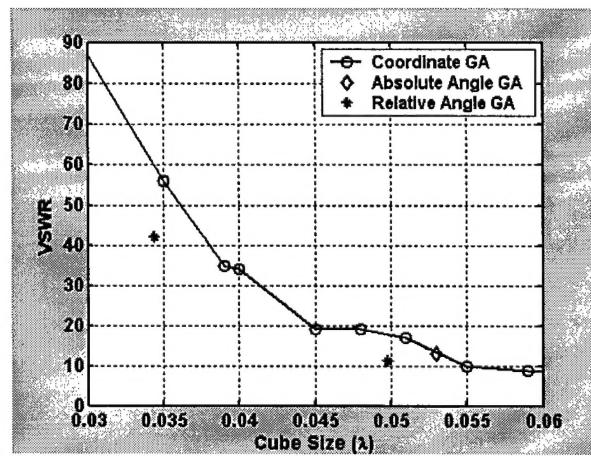


Fig 4: Initial NEC4 simulated results.

that similar improvements are likely for other volumes. While these results have not been confirmed by measurement, three observations are worth noting: First, the absolute angle-based representation (like the coordinate-based representation) was not able to use more, smaller wire pieces effectively in mating. The addition of more wires did not produce better results in either of these representations [1]. However, the relative-angle chromosome representation was able to use more, smaller pieces effectively. Second, once a good antenna length was fixed on, there was very little variation in VSWR between multiple relative-angle runs – the GA consistently produced good antennas. Third, while the coordinate-based and angular based chromosome antennas were not always resonant close to the target frequency (usual variations $\leq 40\%$ of target frequency), *all* of the relative-angle chromosome antennas came out resonant $\leq 1\%$ of the target frequency.

5. Why Does the Form of Antenna Representation Matter?

One might argue that absolute and relative angular chromosomes could theoretically represent identical antennas, if one used identically-sized wire pieces. One could further argue that, by increasing the number of coordinate-based chromosome nodes and getting it to work well outside the positive x-y-z quadrant, it could also yield similar antennas. So what's the difference?

The difference lies in the fact that all of these representations are not equal in their ability to exchange vital information regarding “what makes a good solution good” between different solutions to create better solutions. This is key to how genetic algorithms converge to optimal solutions by combining good pieces (called *building blocks* or *schema*) from different good solutions together [6]. In the three chromosome representations, points, absolute angles and relative angles are different methods of encoding the basic antenna design. It is clear from these initial results, that these methods have different efficacies at exchanging information and ultimately optimizing the antenna layout for this problem.

6. Conclusion

Two new angular genetic chromosome representations for small bent-wire antenna design have been presented and genetic antennas resulting from these chromosomes have been compared with previous work. While these results are too preliminary to suggest that any of these solutions are optimal for given problem, it is clear that genetic representation is significant in genetic antenna design and that all genetic representations are not created equally. The genetic representations presented here each limit the potential solution space to a subset of all possible antenna configurations. Some representations appear better at exchanging good design information than others. It is clear that chromosome design is a crucial step in successful genetic antenna design.

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